Renewable and Sustainable Energy Reviews 102 (2019) 35–53

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects

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ARTICLE INFO

Keywords:
First Access Systems
Microgrids
Rural Electrification
Innovative Solutions for Energy
Leap-frogging in Power Systems
Underserved Communities
Policy making for Sustainable Energy
Renewable Energy based Electrification
Distributed Generation
Social Sciences for Sustainability
Business models for Rural electrification

ABSTRACT

1.1 billion of the world's population still does not have access to electricity in the 21st century. Most of that population resides in the rural communities in developing countries in South Asia, Latin America and Sub-Saharan Africa. Access to electricity can eliminate existing problems related to health, education, social life, economy and the environment, and can increase the income of underserved communities. Most of the yet to be energized regions are in remote, isolated areas, that cannot be serviced through the central grid. While decentralized diesel generators can potentially be installed in these areas, they have a poor effect on climate change mitigation. Clean renewable energy alternatives for off-grid systems are being deployed to reduce the non-electrification rate in the world, and The United Nation Foundation's 2030 Agenda has the objective of universal access to electricity by 2030. While there has been some progress towards that goal, the challenges are countless. If no changes in models, policies and practices are made, the universal access objective will not be achieved, especially in Sub-Saharan Africa that has a level of electrification projection of 30% by 2030. To determine the necessary changes, this paper reviews the rural electrification initiatives in eight developing countries, from Asia to Sub-Saharan Africa to Latin America, and aims to provide an assessment of their success and to discuss the lessons that can be learned and applied on future initiatives.

1. Introduction

Despite the accelerating rate of technological achievements and advances in the developed world, around 1.1 billion of the world's population still does not have any access to electricity today [1,2]. The majority of that population resides in developing countries or in the rural communities of developed countries, in South Asia, Latin America and Sub-Saharan Africa [3]. While most – but not all - urban areas in the world are electrified, 85% of the rural communities do not have that privilege yet [4]. Most of the yet to be energized regions are in remote, isolated areas, which makes extending the central grid to service them quite infeasible. Furthermore, small island nations are geographically confined and have to consider building smaller power systems [5]. Lack of electricity is correlated with many issues found in underserved communities, such us poverty, hunger and gender inequality [6]. Non-electrification acts as a barrier to economic growth and social progress, but it can also initiate many problems and challenges related to the quality of life in the rural regions [7]. While decentralized diesel generators can potentially be installed in these areas, observational studies have shown that the varying cost of the fuel can be costly, as well as the maintenance of the generators [8]. Above all, diesel generators can negatively impact the fight against climate change through greenhouse gas emissions, and that is an issue that cannot be neglected today [9]. Clean renewable energy alternatives for off-grid systems are being deployed continuously to reduce the non-electrification rate in the regions that cannot be serviced through grid extensions, until a 100% electrification rate is achieved [10]. In fact, The United Nation Foundation's 2030 Agenda has the objective of universal access to electricity by 2030 [11]. While there has been some progress towards that goal, the challenges are countless. Section 1.1 will discuss the benefits behind universal access in some detail, and Section 1.2 will highlight the main challenges that can act as a barrier to reaching this goal.

1.1. Universal access benefits

Universal electricity access can eliminate a wide range of existing problems in non-electrified regions that are related to health, education, social life, economy and the environment. Poor communities that are not provided with electricity have no other option but to depend on traditional biomass for everyday cooking and heating, which poorly

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https://doi.org/10.1016/j.rser.2018.11.035
Received 11 December 2017; Received in revised form 30 October 2018; Accepted 22 November 2018
Available online 06 December 2018
1364-0321/

affects the life expectancy of the women and the children that are exposed directly to the burnt wood [12]. Burning wood extensively also leads to deforestation which can hurt the sustainability of the environment [13]. Cooking and heating with electricity can eliminate these problems. Electricity can also replace the use of kerosene lights, and consequently reduce the number of accidents caused by them, including fire burns and severe health conditions such as lung diseases, tuberculosis, poisoning and cataracts [14,15]. Fire-related deaths exceed 300,000 annually in the developing world [15]. Also, without a reliable light source, some operations in health services can be extremely difficult, especially infant delivery surgeries. Some emergencies need to be handled during the night, but if health centers do not have any lights, these services can be limited. That is 1.1 billion people that do not have the privilege of being treated in a health facility that has access to electricity. A fourth of Kenya's health facilities and almost half of India's experience frequent blackouts and disturbance in patients' treatments [16]. From an educational perspective, the level of literacy can be closely related to the accessibility of electricity for similar reasons. Many students require extra hours of study to strengthen their grasp of the studied material during school hours, but they are unable to spend that time due to the lack of indoor lighting in their homes [17]. They also do not have the option of going to an after-school program, for the rarity of these programs, since most schools are also not energized during night time, and therefore have no source of lightning nor heating during cold nights. With electricity, other resources can be available, such as computers and internet connection.

Electricity can help create jobs and improve the socioeconomic situation in the developing world. It can open businesses that would otherwise be impossible, directly and indirectly, such as computing services stores, but also restaurants that can utilize refrigerators, to name a few. In the other direction, the lack of electricity can lead to economic unproductivity [18]. For instance, the Papua province in Indonesia is rich with a variety of natural resources such as water, fisheries and minerals, but utilizing these resources is difficult without energy access, which explains the high levels of poverty in that region [19]. The success of the agriculture sector is crucial for a growing economy and an increase average income in developing countries as it accounts for 29% of the GDP of these countries and 65% of their labor force [20]. However, to rival agricultural resources from the developed world, these countries need to adapt methods and technologies that can increase their yields and manage their agricultural supply chain. Other aspects of quality of life improvement relate to social and cultural benefits. For example, evening gathering to exchange news and stories are traditionally important in the Humla Community in Nepal, but can be dangerous to practice routinely around a fire for the reasons discussed earlier, and can also be an annoyance that might limit the social gatherings in the community [13,21].

All these benefits make the goal of universal access attractive and depending on clean energy sources instead of conventional fuels would also help with the sustainability of the planet [22]. The percentage of electrification would be much higher in the developing world today, if the process did not include various challenges and limitations. After all, there are still 1billion plus people who have not experienced the benefits of electricity yet. Many factors contribute to the barriers and the slow progress in this field. One of them is the lack of a supporting policy framework. This field is very dynamic, involves a lot of innovation and brings about novel challenges to market that require new mechanisms to be developed [23]. There is census in the literature that these benefits can only be reaped when the sector receives the support of a well-developed policy framework [24]. This requires understanding this new and unstructured field thoroughly, document previous experiences and extract the lessons learned for future implementations [25].

1.2. Rural electrification options and challenges

There are many options for providing electricity in the rural areas, that account for most of the unelectrified areas today. Grid extension has been the mostly adapted solution until it became no longer feasible due to the geographical disparity nature of many of these areas that would not be able to justify the cost of transmission, as well as the small demand and load profile in these regions [26]. For example, at least 20% of the Indian rural communities, if not more, cannot be reached through a grid extension solution, from a financial standpoint [27]. The centralized grid introduces vulnerabilities today to terrorist threats, climate change and natural disasters [28]. There are off-grid solutions that are based on either small isolated generation and distribution networks that are directly connected to the customer's home and do not provide all potential electrical applications but some of the necessities, such as photovoltaic systems that can provide lighting only [29]. Since the central grid in developing countries is in itself weak and unreliable [30], it is preferred to avoid overloading them and to switch instead to renewable energy based off-grid solutions [31]. This challenge brings along some opportunities, where the very concept of power grid can be redefined according to one's needs [32]. For energy access space, this can vary between solar home system, mini-grid, microgrid and utility grid extension. This multi-layer structure is new to energy field and needs novel assessment approaches such as multi-tier framework employed in Cambodia, recently [33]. In addition to this, a global tracking framework has been developed to track global progress towards energy access in a sustainable way [34].

Unfortunately, off-grid solutions are still faced with many financial, operational and technical challenges [35], which in most cases require the help of the private sector that are rarely willing to tackle these challenges without clear outcome. The private sector is mainly concerned with the regularly changing or poorly-defined policies that might add ambiguities to their responsibilities or expectations [36]. Recent reports show that a stable policy framework that supports deployment of renewable energy based microgrids is very crucial [37,38]. Countries that have a clear and supportive energy access policy get more investments from international organizations [39]. Because of this fact, there are valuable publications that document policies that yield positive outcomes [40]. Other reports detail the power system reforms that followed administrative ones [41]. International Energy Agency's special reports on energy outlook of certain locations, e.g. India [42], Africa [43], and Southeast Asia [44]], include key indicators about the future of energy systems therein. These indicators show what energy sources may be utilized more and what policy mechanisms enable their inclusion in the overall strategical planning. In relation with these, sustainable development goal indicators [45] and regulatory indicators developed [46] can be used for better planning. There are documented results where countries were able to accelerate first-access deployments by clearly setting out their energy roadmaps and policies, such as Tanzania [47] Maldives [48] and Philippines [49]. International Renewable Energy Agency (IRENA) has been closely following such efforts and document methodological issues [50] and approaches that accelerate off-grid renewable deployments [51].

There is also very little information on the expected level of demand of the microgrid's customers before implementing the project [52]. This is very crucial for off-grid solutions since if the demand is lower than expected the providers would gain more losses than profits, and if it is higher than expected, the project would not be sustained due to customer's dissatisfaction [53]. There are innovative approaches to tackle these issues where digital technology [54] and big data analysis are utilized to come up with more realistic demand forecasts [55]. Getting correct data and successful continuation of the electricity projects highly depends on participation of the local community [56]. Due to their isolated nature, these communities may be in a volatile situation and the developed energy solutions need to take this into account [57].

Using renewable energy, despite its benefits, is also challenging. While the cost of fuel is relatively low in renewable energy generators, the upfront cost is significantly high in the case of microgrids [58], and without a stable source of fund the electrification program cannot

commence. Also, as of now, most developing countries do not support renewable energy generation with reliable RE policies and therefore adds complications to the development of these projects. If nothing changes in the practices, policies and models used for electrification, the level of electrification projection for 2030 would be 80% in Latin America, 68% in Indonesia (almost universal access in the rest of South Asia, but not fully), 82% in the Republic of South Africa and only around 30% in the rest of Sub-Saharan Africa [59].

One of the biggest hurdles in first-access energy projects is the financing. Feasible and sustainable financing schemes are required for the success of these projects once technical, environmental and political circumstances reach a mature state [60]. The ultimate question for private investors is the financial viability of the projects, i.e. cost recovery [61]. Policy makers are trying to make these projects viable by taking different approaches with mixed results. There are models based on giving concessions [62], providing subsidies [63] or providing donor funding from multilateral banks [64,65]. A key piece of the puzzle is to create and nurture an energy market for the long-term success of first access systems [66,67]. The past experiences have been with mixed results, although the prominent model is the bottom-up approach, where first access systems start small and extend as the market and financial viability grow along with it [68].

It is clear from the above discussion that changes are required to tackle the challenges of renewable energy rural electrification, which can only be achieved by assessing the success and failures of previous electrification initiatives and discussing the lessons that can be learned from the process of their development, implementation, maintenance and expansion, to weigh the technical, commercial, financial, social, environmental and policy-related options for future electrification initiatives.

2. Case studies

This paper will review the numerous rural electrification initiatives in eight developing countries throughout the world, from Asia to Sub Saharan Africa to Latin America. Fig. 1 shows the countries selected for case studies. Table 1 describes briefly the various initiatives in the corresponding countries, regions, and time periods, the applied contribution or model of electrification and the utilized source of renewable energy, if applicable.

2.1. Brazil

Although 97% of Brazil's rural areas are electrified, more than 38% of the Brazilian amazon is yet to be electrified [69]. This equates to more than 600 thousand households that need to be attended with regular power [70]. What makes the electrification process in the Brazilian amazon difficult is the dispersion of communities, due to the geographical constraints of the rainforest; the lack of an infrastructure of roads and commercial and financial services limits the assessment and usability of the electrification services [71]. To understand the different stages of electrification initiatives in Brazil, it is important to note that Brazil is composed of a federation of states, and the power is divided into two main categories: federal-owned and state-owned. The electricity sector has also experienced this divide, with generation companies being federal-owned, and distribution companies being state-owned [36]. During the 1990s, the electricity sector treated electrical power as a commodity rather than an integrated service [72]. State-owned distribution companies were no longer restricted to provide power equally but instead focused their efforts to increase their economical profit and target high-demand areas. This division of the sector and the characterization of electrical power as a commodity privatized the generation and access of power and eventually backfired when Brazil faced a major electricity crisis that led to blackouts and a struggling economy, due to the lack of the ability of cross-subsidizing and generation expansion.

Since the electricity crisis and the failure of the privatization model in 2001, the federal government switched its efforts completely, and aimed for a universalization model of electrical power throughout the country that can promise power services to all residents, regardless of

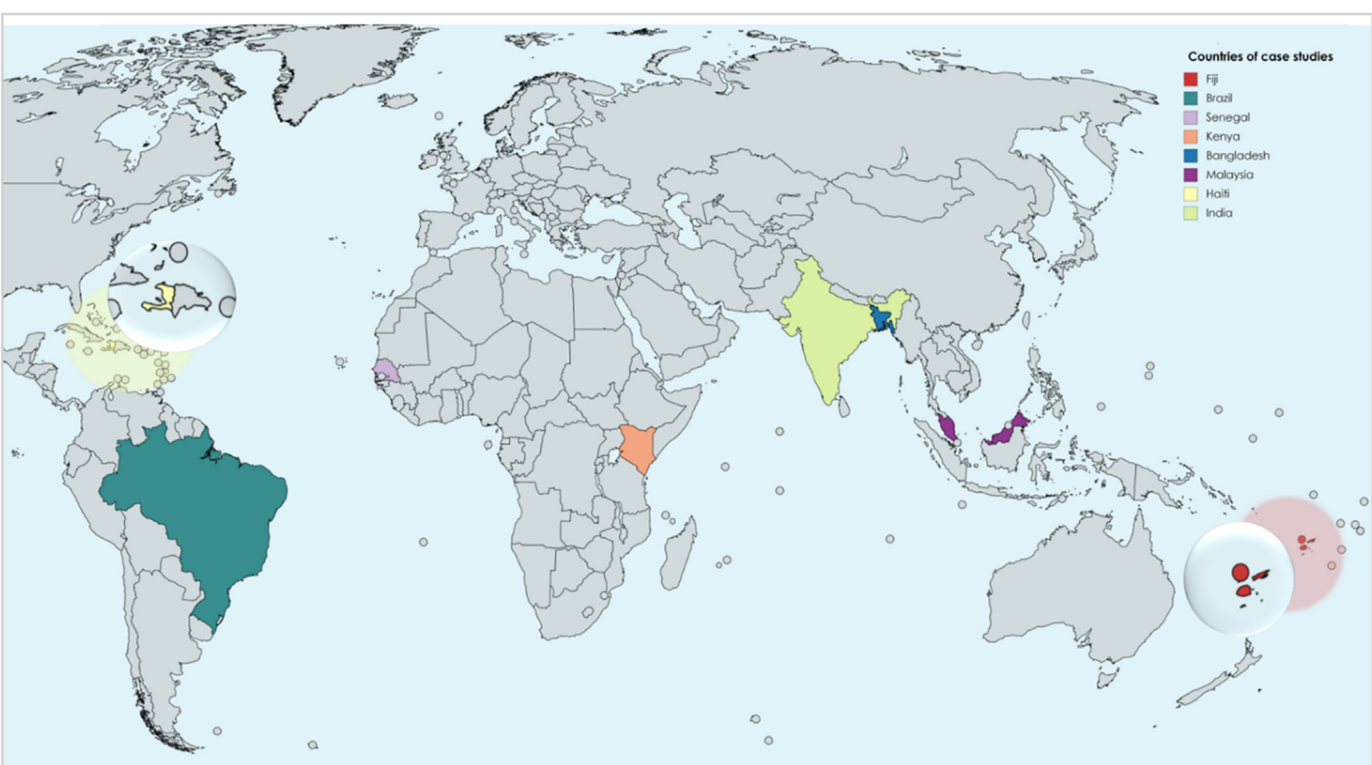

Fig. 1. Countries selected for case studies throughout different regions in the world.

Table 1
Summary of rural electrification initiatives in developing countries under review.

Initiative/Developer	Country	Main Region	Year	Electrification Model	Renewable Energy Source
WTP	Brazil	Amazon	1990s	R&D	NA
Prodeem	Brazil	Amazon	1994	Stand-alone	PV
LfA	Brazil	All	2003	Stand-alone	PV/Hydro/Hybrid
IDCOL	Bangladesh	–	2002	Stand-alone	PV
FEA	Fiji	Vunivau	2002	Stand-alone	PV
EDH	Haiti	Sud/Grande Anse	1986/2009	Microgrid	NA-diesel
CIP	Haiti	Caracol	2010	Microgrid	NA-diesel
GE/Tonibung	Malaysia	Borneo	2005/2009	Microgrid	Hydro
HPS	India	Bihar	2010/2012	Microgrid	Biomass
DESI	India	Bihar	2006/2012	Microgrid	Biomass/Hybrid
IEE	Senegal	Kaolack/Fatick Thies	2009	R&D	Solar/hydro/biomass
MEP	Kenya	Mpeketoni	1994–2007	Microgrid	N/A

social class, geographical constraints and/or economic abilities [73]. Many attempts have been made in various directions to reach this goal, from research and development programs to power generation implementations as well as novel street lighting projects [74].

2.1.1. WTP – wet tropic program

WTP, or the Wet Tropic Program, is an R&D initiative on decentralized generation that was implemented by the Ministry of Science and Technology in the 1990s. This program explored and financed the use of renewables as an energy source in the wet tropics, especially for photovoltaic energy [75]. This program was a milestone in the use of renewable energies for providing power in the Amazon region, because it acted as an R&D infrastructure and financed the renewable energy laboratories that helped unelectrified communities with developing electricity generation projects. Due to the efforts of WTP, communities in the region were financed to generate electricity, with a more notable success for community projects that received more than one provision of funding to allow the integration of the electricity generation initiatives into local development initiatives. The WTP was an R&D program independent of the electricity sector, and the only governmental R &D program the encouraged the use of renewable energy in the Amazon region [75].

2.1.2. Prodeem - the Brazilian program for rural electrification using photovoltaics

During the same period, Prodeem, a photovoltaic systems installment program, was proposed and run by the Ministry of Mines and Energy starting from 1994 [76]. Like WTP, no clear participation of the electricity sector was observed in Prodeem. The focus of the program was the unelectrified rural communities that are outside of the range of the centralized grid. In the nine years Prodeem was under operation, it managed to install 6000 photovoltaic systems and to acquire 3000 more systems, although there is no guarantee that all 9000 systems had been installed then [77]. This benefited just under 500 communities in the Amazon. Other than PV systems, two micro hydropower plants have been installed by Prodeem through national manufacturers, but it did not invest more than 0.18% of its total resources on the hydropower plants [75]. The PV systems installments did not make a good use of national industry but was rather executed through an international public bid that required a total dependence on imported equipment. The only part of the project that was related to the PV systems that was run by the national industry was the battery supply and other minor parts that do not require technological complexity [78]. The reliance on international rather than national resources and services caused several problems in the installment and maintenance and the operation of the systems. Prodeem did not account for the need of spare parts in the event of failure of initially imported parts, or more importantly, the need for qualified technicians that can maintain the equipment locally [79]. Therefore, Prodeem could not provide long-term sustainability.

2.1.3. LfA - Luz para todos (light for all)

Unlike WTP and Prodeem, Light for All (LfA) was a pure national initiative planned and executed through the electricity sector in Brazil, mainly by the Brazilian Electricity Company (Eletrobras), with the involvement of both the federal and state governments [80]. It started in 2003 with the goal to, as the name implies, electrify all of Brazil, and it reached most citizens in the country by 2009 [81]. One of the main strengths of the program is that, since it was a national effort, it allowed community representation. LfA mainly focused on rural electrification through the extension of the national grid. However, because there are completely isolated areas that are hard to reach through this method, the grid extension solution became almost impossible after LfA's preliminary push [82]. The program, then, allowed decentralized generation through locally implemented renewable energy microgrids, especially in the Amazon region [80,83]. The companies that were mainly responsible for this project were part of the energy sector that traditionally work with grid extension; therefore, the new decentralized projects added operational and technological challenges to this initiative, because of the lack of experience in the field of decentralized electricity generation with RE. The government, looking for technological expertise to tackle these challenges, turned to the universities and research institutions for tentative plans for decentralized electrification with renewable energy projects. This makes LfA the first joint effort between the Ministry of Mines and Energy and the Ministry of Science and Technology [82], which fills the communication gap experienced by previous initiatives. The academic institutions proposed multiple projects to help the government with its execution of grid extension alternatives, shown in Table 2.

Due to the novelty of these projects in rural communities in Brazil, the citizens in these areas will need a long time to be familiar with the installed systems, but after a few rounds of assessments of these projects, it has been shown increasing success in some projects, those that started with a strong social community involvement and individuals trained by the research and development team to manage and maintain the operation of the electrical systems installed. In general, LfA faced the traditional challenges imposed on rural electrification and helped expand the domain of technologies beyond what had been widely employed in the country in the past. With community involvement and the joint efforts of the government and research institution, the initiative led to a huge socioeconomic development.

2.1.4. Lessons learned from Brazil

We can infer from the Brazilian Amazon experience a few lessons that can be applied on future electrification projects:

– The role of universities and research institutions is essential for a change in the paradigm: Technological challenges require the expertise of skilled individuals that cannot be trained without the efforts of the research and development teams. However, the participation of these teams cannot show results without a mutually

Table 2
Grid extension alternatives for LfA electrification project in Brazil. [24].

Technology	Description	Projects
Hydrokinetic turbine	1 kW hydrokinetic turbine for community use	1
Micro hydropower	50 kW micro hydro from local Amazonian turbine manufacturer	2
Stirling motor	5 kW stirling motor with biomass	1
Steam turbine	Production of electricity from waste wood in 200 kW steam turbine	2
Biodiesel	Production of biodiesel from vegetable oil	3
Hybrid solar, wind and diesel	Revitalizing a 2 kW diesel and two 10 kW wind turbines	1
Hybrid solar and wind	Installation of 3.3 kWp PV with 1 kW wind turbine	1
Biomass gasification	Gasification of Assai waste (Euterpe oleracea)	
PV	19 kW PV for residential use	2
Vegetable oil	Use of palm oil in 92 kW diesel motors	2

understandable communication between them and the government. The government needs the academic help of research institutions and, similarly, the work of research institutions needs to be recognized and coordinated through the national government to provide any feasible change.

– The integration of local development initiatives: from all three initiatives discussed, we see that the community involvement is needed to ensure long-term sustainability. Prodeem had the potential to be a successful project but it relied on imported equipment rather than the national industry, and it did not account for maintenance issues. Without local skills and qualification, the electrification initiative can fail on the long-run. LfA, on the other hand, showed potential in this regard for doing exactly the opposite of what Prodeem has done. However, R&D teams should be aware of the difficulties that come along training individuals from isolated communities, since it is highly likely that they are illiterate and have no initial knowledge on the subject. It might be beneficial to have a rural electrification agency or a special agent situated in these communities, to note any development issues and to promote rural electrification with decentralized generation [84].
– Precarious systems inclusion: it is important to note that various rural communities in Brazil have precarious systems, that is: systems based on diesel generation that are maintained by the community itself and are not registered or recognized by the federal or state government, since these services do not meet the basic requirements of the electricity sector [85]. With the economic and institutional support and participation of the electricity sector, these grass root initiatives can be expanded and developed to, on the one hand, electrify a larger portion of the country, and on the other hand, ensure local communities participation and as stated earlier, a long-term sustainability.

2.2. Bangladesh

Bangladesh has reached an electrification rate of 75% in 2018 [86]. However, the situation was much different until recently, since more than 2/3, or 67.5% of Bangladesh had no access to electricity as of 2008 [87]. Electrification solutions in the remaining third of the country were often unreliable which results in a generally weak energy system. The regions that have no access to electricity are isolated, and that again raises the discussion of the need for decentralized microgrid solutions versus the extension of the centralized grid. The most notable rural electrification initiative in Bangladesh is the IDCOL program that begun in 2002.

2.2.1. IDCOL program

IDCOL is the Infrastructure Development Company Limited, a financial institution that provides financial support to renewable infrastructure projects located in Bangladesh. IDCOL received help from the World Bank to initiate the development of its project, as well as 16 partner organizations (POs) [88]. The main focus of this program is installing solar home systems to benefit the rural communities in Bangladesh that have no feasible means of accessing electricity. Although the program aimed to install 50,000 solar systems in its first 6 years, it managed to almost double its goal with the installment of 93,600 systems by 2008 [89].

The partnership between IDCOL and the POs worked in the following manner: IDCOL provides the financial needs of the installments cost, training POs to operate and maintain the solar systems, specify the technical requirements of these systems and publicize for the program. The POs apply the training they have received and select the most preferable areas in terms of demand, and take care of the installments and maintenance of the systems. They also extend their training to prepare local citizens with the needed qualifications that makes the communities ready for its maintenance and ownership. Similar programs tend to select individuals that are less likely to migrate to cities after they receive their training, such as a rural electrification initiative in Tanzania that chose to train grandmothers in India, predicting their return to their homeland to apply these skills [90]. Fig. 2 shows the IDCOL business model and the interactions between IDCOL, international organizations, partnership organizations and customers.

The implementation of the program had many successful factors but also weak points. According to the responses of a survey to the citizens of the rural communities that benefited from this program, the majority (90%) thought that the inclusion of the local communities in the process of maintenance and ownership of the installed systems significantly reduced the maintenance costs long-term [91]. The availability of the knowledge of managing these systems eliminates the need for reoccurring professional technician visits to the rural site. The respondents placed higher importance on maintenance and monitoring knowledge than on in-house technical instructions. Also, 40% of the respondents suggested that the availability of power in their households contributed to increasing their income either directly or indirectly [91].

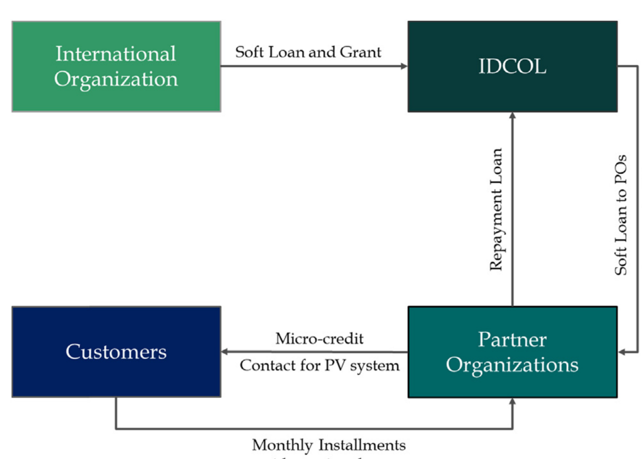

Fig. 2. IDCOL business model [84].

The weakness of the program lies mostly on the non-collaboration of the government, especially in terms of energy policies' support. The government's policies on energy do not push in any way for systems operated by renewable energy. However, tax-exemption on renewable energy products provided a positive impact on the development of the program as the cost of the PV systems reduced significantly. Current renewable energy products require constant development with the support of research and development teams, but there is a lack of financial and policy-related support from the government that acts as a blockade to the growth of the renewable energy market in Bangladesh [92].

2.2.2. Lessons learned from Bangladesh

In terms of policy, the discussion of government support of RE policies suggests that having no direct program focused on energy access and no or low government involvement at the early stages of a renewable-energy-based electrification project can significantly slow the process of development [93]. Increasing private sector participation is important for expansion but the basis relies on government support. In terms of institutional framework, according to the survey of the rural communities, electrification initiatives should focus their effort on maintenance and monitoring to guarantee the longevity of the PV systems or any other form of electrification system. If the maintenance and monitoring are run by locals who have private ownership over the systems, the cost of these operations can be quite minimal while still being functional and beneficial to the locals themselves. The systems should be designed as needed by the customers to increase demand and to avoid situations where the customers are unable to pay for the designed system; a situation where both the producer and potential consumer suffer.

Finally, politics, as we will see in later case studies can have a huge role in the development of any electrification initiative. In the case of Bangladesh, before the IDCOL program there had been other solar system electrification projects that have been abandoned by the government because of the promises of the energy minister in the country at the time to extend the centralized grid [94]. Obviously, these promises did not manage to be fully met and many isolated communities remained unelectrified, but politics have tremendous power of the direction that any initiative can take, especially in developing countries where the people are bound by strong political situations.

2.3. Fiji

Fiji is a relatively small country with a population of about 900,000, that is classified as an upper-middle income country, and is continuously experiencing growth in its industries, especially in mining, construction and manufacturing [87]. However, all of these industries require an intensive amount of energy, which creates a tradeoff between providing for the growth of the economy and for the accessibility of power for all its people. The latest data show that there are 4% of the urban population that remains unelectrified, and approximately 20% of the rural population that cannot benefit from the extension of the central grid [95]. Another challenge that faces Fiji is the heavy dependence on imported petroleum, which fluctuates in price and negatively impact the expenditure of the country on its energy resources. Most importantly, the 23rd annual Conference of the Parties to the 1992 United Nations Framework Convention on Climate Change (COP23) was presided by Fiji, an island nation that is considered one of the most vulnerable nations to climate change and rising sea levels in the world [96]. Numerous global warming challenges are particular to Fiji and other similar nations geographically, and that can highlight the urgency of moving towards renewable energy sources for their electrification projects.

2.3.1. Vunivau - Fiji electricity authority program

The Fiji Electricity Authority, or the FEA, has a program that aims for the universalization of electrification in its country. This program ran in Vunivau between 2002 and 2005, and two surveys have been conducted to measure the success of the program; the first was in 2003, while the program was still in progress, and the second was three years after it had ended in 2008 [97]. The program was a joint effort between the Fiji government and the Japan government with the goal of reaching sustainability and development of energy services. Because of the negative impact of the heavy reliance on imported petroleum-based fuels on the economy, the FEA program decided to rely on renewable energy sources. The program installed PV systems in Vunivau, all were the same size of 100 W [98]. To implement the program, the government, with the support of international organizations reinforced the Department of Energy financially, and this department took care of managing the electrification plan and was the primary point of contact with the Rural Electricity Service Company (RESCO). RESCO had the tasks of installing and monitoring the systems, and had the most direct contact with the users of the systems, including the collection of tariffs from them [99] This is because the program was owned by the government rather than by the people, who had to pay a monthly tariff or fee-for-service to rent the installed systems.

The financial process worked as follows: each household needed to pay 14 dollars to top up a voucher card, with half a dollar service fee and the rest goes to the operations and maintenance of their system [99]. The government finances the initial capital cost of the systems. On the other hand, the government has a policy that also enforces import duty on PV systems, unlike the tax-exemption policies that have took place in Bangladesh [95]. This makes the shift toward renewable energy sources extremely more difficult as it is a policy that does not attract private investors to invest in the renewable-based projects run by the government of Fiji.

The 2003 and 2008 surveys showed completely different results. The one conducted in 2003 showed a relatively positive image of the program by 85% of the users that took the survey [100]. The most attractive part of the initiative to the customers was the fee-for-service model that makes it feasible for the poorest people to pay for the service as they need it. Also, they showed a general satisfaction with the maintenance of the systems as RESCO took care of it during the time of implementation. In general, when people were asked about their opinion on the program as it was still under creation, they thought that the program was a successful initiative and provided a better environment for them socially and economically. However, five years later, and three years after the end of the program, the responses showed no sign of satisfaction and the opinions of the users were the opposite of what they initially thought, which suggests the failure of the program in the long run. 80% of the PV systems failed during these three years [88], mainly due to the fact that there was no local technician to take care of them. RESCO was responsible of all tasks related to monitoring and maintenance during the first stage of the project, but that effort did not continue and was abandoned once the program had concluded.

2.3.2. Lessons learned from Fiji

The initiative did not prepare the villagers to maintain the systems independently, which caused their rapid failure and the inability of the communities to reverse that failure or have someone do it for them. This is the opposite of what happened in the IDCOL program in Bangladesh, and unsurprisingly, the results of the programs were opposites as well. This emphasizes the importance of community capacity building, of qualifying the communities to support themselves and contribute to the success of the electrification project in their area. Without post-sales service or a pre-training of the locals, an electricity network cannot survive. If an organization starts with enough money or grants to cover the cost of the project, but it does not ensure that it would be continuously maintained, then the project could eventually be crumbled. It also decreases the faith of the consumers in the technological resources that they were provided with, as they would most likely blame the technology than themselves for any failure that occurs.

Other lessons to be learned relate to the use of financial policies and subsidies. The subsidies should be structured in a way that makes it feasible for the poorest consumer to benefit from the installed system while still requiring the financial contribution and collaboration of all customers. Fiji is also not the only country that should shift to renewable energy, as it is more important now than ever to reduce the CO2 levels in the atmosphere and sustain our earth. Besides sustainability-related reasons, the cost of transporting diesel continuously to a diesel-based generator in an isolated community is costly, and it can eventually drain the national resources [101]. Countries that aim to implement new initiatives for electrifications in areas that do not have access to electricity yet should work on creating a masterplan for electrification using renewable energy power generation, and spend a sufficient time in planning for a successful project that not only shows immediate success, but one that has the capacity to support generations. This is not only for the benefit of the people but also for the benefit of the governments and could potentially lift the heavy weight on their economies.

2.4. Haiti

According to the latest World Bank data, only 37.9% of Haiti is electrified, an increase of less than 9% in 24 years, or 0.375% a year [87]. This is considered relatively slow process and significantly low rate of electrification compared to the world's average of 85.3%. Given that Haiti is one of the poorest countries in the world, with less than a dollar for the average annual income per capita [102], electricity can open doors for Haiti by creating opportunities to increase the national income. The country has an electrification goal of 50% rate by 2020, which requires new practices and initiatives that can accelerate the current rate of access. The republic does not own one central grid but it rather has 10 regional grids [103]. The national electrification utility in Haiti is Electricité d'Haïti, or EDH, which is a government-owned body that is responsible for 72% of the power generating capacity and 100% of the transmitting, distributing and marketing of electricity [103]. No other utility in Haiti has authorization to sell electricity to the citizens. A few Independent Power Producers (IPPs) own the remaining 28% of the power generation in a couple of the regional grids [104]. EDH started as a private firm in 1971; however, 18 years later it was nationalized by the government [105]. The electrification of the rural communities in Haiti is also the responsibility of EDH, but as observed, the execution is not promising. Only 35 communities have been electrified by EDH through microgrids in the past 30 years [106]. EDH does not publicize the details of its projects either, which makes studying them difficult.

2.4.1. Electricité d'Haiti - EDH program

Multiple site visits have been made in 2012 by a United Nations Foundation team to some towns in the Grande Anse (Pestel) and in the Sud (Coteaux, Port-a-Piment, and Roche-a- Bateaux) states of Haiti to measure the success of the electricity systems installed in 1994, 2008, 2009 and 1986, respectively [107]. All systems used diesel as the power generation source and were found to be not functioning properly, with high theft and loss rates, and acted as a barrier to the growth of the Haitian economy. Some of the findings through these visits are listed in detail [108]:

2.4.1.1. Development and implementation.

– According to the surveys and interviews, communities can request their electrification needs through the mayor of the municipality, who would get in touch with the department of rural electrification through a letter with the request of the specified community. The letter then goes to the Ministry of Planning and the Ministry of Public Works. A technical team goes to the community to look over the site and write a report on it that assesses the needs of the people and the estimated budget through surveys. This report is sent back to the mayor who now directly contacts the Ministry of Planning to request funding. The ministry makes the final decision on the method of funding of the electrification project: bids from private contractors or redirect the financial requests to the EDH.
– The operation of the project's systems is the responsibility of the municipality, either through an independent local committee or an independent non-profit organization, and the installation and maintenance of these systems is the responsibility of the EDH. The project is partially owned by the municipality, but not fully. The municipality has ownership over the installed microgrid system and the source of generation. The land of the microgrid, however, is not owned by the municipality. The EDH labels the land as a public utility and takes ownership over it, and their justification behind this is to lessen the chance of the mayor selling the land.
– Since the municipality technically owns these systems, it has to cover the costs of operation, and there is no guarantee from the government that it would send compensations to the municipality for the operations of these systems. Since the documentation on the projects are not publicized, it is hard to obtain accurate and reliable information on the financial operation of the projects. The interviewed mayors and deputies suggested that the members of the upper house of Parliament in Haiti finance the projects partially from their "discretionary funds", and community fundraising and the contribution of the government pays for the rest of the costs [109]. The distribution of the contributions is unknown. One of the directors at EDH, however, provided different answers. According to him, the Ministry of Planning and the EDH itself cover the financial costs of the project's implementation and expansion [110].

2.4.1.2. Performance.

– During the site visits, data loggers were placed on the microgrids in Coteaux and Port-a-Piment in the Sud state, to measure their performance. The battery in these loggers were not monitored as frequently as it had been necessary since they died for extended periods a few times. Nevertheless, during the active logger periods, which was about two-thirds of the year, the systems were only functioning for 66 days Coteaux (28% of the time) and 28 days in Port-a-Piment (10% of the time) [107]. The results are shown in Figs. 3 and 4 for Port-a-Piment (Left) and Coteaux (Right). Even when the systems were functioning, they operated for less time than scheduled.
– The low connectivity is mainly due to the lack of financial capability of the operators. If the operators cannot afford the cost of the fuel to generate power, the systems naturally cannot operate. Similarly, if any of the systems fail, and the operator does not have the necessary funds to repair them or to provide spare parts, long periods of non-functionality become inevitable. Only when the EDH decides to

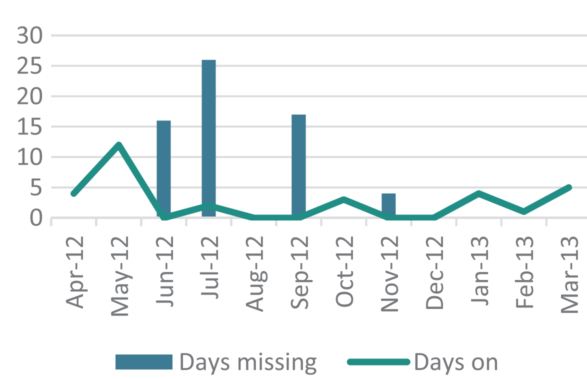

Fig. 3. (Left). Data loggers' measurements for Port-a-Piment microgrid functionality throughout the year.

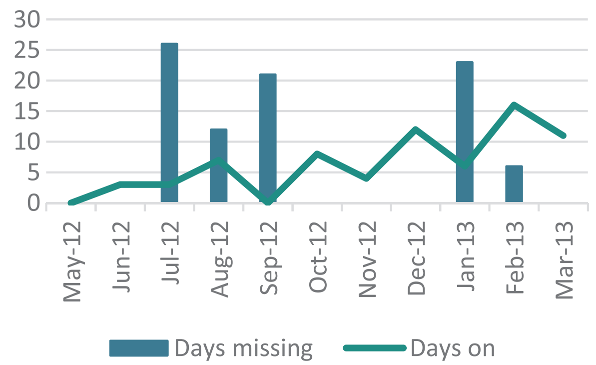

Fig. 4. (Right). Data loggers' measurements for Coteaux microgrid functionality throughout the year [107].

provide that support the systems can keep running, and sometimes it takes days or months before that happens. It seems, however, that the customers usually have a high willingness to pay whenever the systems are working. On the contrary, the rate of willingness to pay decreases significantly when the systems fail. This might seem obvious, but it is important to understand that in many poor communities, there is always a belief that the customers are not willing to pay for the services they receive because they cannot afford it, and consequently try to take advantage of the systems without paying for them. This might be the case for poor communities in populated cities, but not for isolated rural communities, such as the Haitian communities, that prove otherwise.

– Another flaw found that is more related to the general execution of the projects rather than the functionality of the systems is the political favoritism that plays a role in the selection of electrification sites and the maintenance of the microgrids. The director of the Bureau des Provinces that works with EDH confessed that the selection process of the microgrids that would be serviced by EDH, or of the communities that would receive extra fuel or repairs, is biased and favors communities with mayors that have similar political opinions as those of the EDH [110].

2.4.2. CIP - caracol industrial park

In January 2010, an upsetting earthquake struck Haiti and its aftermath required the support and attention of the international community [87]. This is when the construction of the Caracol Industrial Park (CIP) in the Caracol Community of Haiti took place, through a co-sponsorship between the Haitian government, the U.S. government, the Inter-American Development Bank, as well as a number of private investors [111]. The development of this community happened with the objective of improving the quality of life of its residents, as well as enhancing the economic growth of Haiti. USAID sponsored the design and construction of the project power plan with the help of ESD Engineering, an engineering firm. The National Rural Electric Cooperative Association (NRECA) also showed its support and helped the EDH with repairing damaged microgrids for loss reduction and power restoration, by sending a professional engineer with high qualification to the technical department of EDH. The project took two years and a half before the power plant commenced its functions [112].

This project created many jobs that would otherwise not be existent, and the benefits extended to the neighbors of Caracol which sums up to more than 2269 customers/households, and potentially many more Haitians (Table 3). The industrial park also has 2000 workers currently and more jobs are being created every day [113]. As a consequence, many families started to have significantly better income. For example, the reliable electrification allowed the creation of small independent businesses in the complex, such as Cyber Café, a small shop that sells office equipment, provides computer and internet connection services

Table 3
Number of customers with electricity access in Caracol and neighboring communities [62].

Community/Project	Completion Date	Access provided for customers
Caracol	January 2013	696
Jacquezyl	May 2013	348
EKAM	August 2013	754
Cahess	April 2014	136
Madras	May 2014	405
University Route 6	June 2014	230
Subtotal		2269

to its customers and has a printer and a laminator for printing, copying and laminating services [114]. Another example is a beverage store that solely sells cold refrigerated refreshments.

This program also proved that the residents are more appreciative and more than willing to pay for a good service. Unlike the payment rate for the services provided by EDH in which most systems are not functioning, the CIP project usually has 95–99% rate of tariff collection [114]. This is mainly due to the reliable electricity provided by this project, the respectful relationship between the customer and the provider, as well as the strict punishments of disconnection when payments are not completed.

2.4.3. Lessons learned from Haiti

Many lessons can be taken away from the Haitian electrification experience, from social, financial and policy perspectives:

– Noncooperation with researchers can add unnecessary complications and setbacks to the electrification process. The analysis of the EDH program could not be optimized since all documentations kept private, which adds unclarity to the successes of the projects and the challenges they could be facing. Site visits are a good option to compensate for this lack of formal information, but can lead to biased opinions and a clash of point of views.
– Payment collection is nearly impossible without providing reliable electricity. As any other customer, all rural communities want is a guarantee of continuity of service in the event of a completed payment. There is an obvious cyclic relationship between functionality and payment, and customers usually keep their end of the deal, the payment, as long as the service remains operational. Both initiatives show this result clearly.
– During the site visits of the UNF it was found that the EDH has oversized generators that can provide more service than the customers need, let alone pay for [115]. Governmental and national utilities do not consider size-measurements to the same degree as for-profit organizations that carefully employ these measurements to not overpay for the project and to maximize their profits [116]. The size of the generators increases the operating cost of the systems, which makes it more difficult for the operators to cover the cost of the unnecessarily high amount of fuel in the given region. As a result, it causes dysfunctionality more often than not, less willingness to pay from the customers, and it distorts the order of the cyclic relationship discussed. Smaller generators would solve this problem. It is important to note that picking the right size for these generators require a significant amount of studying and planning of the electrification project site, which the EDH program seems to lack.
– EDH depends on diesel mainly for generation. Haiti is one of the countries with the lowest levels of electrification and a transformation in the direction of clean renewable energy is crucial in this case [112]. Many developed countries are trying now to shift previously-constructed systems to renewable energy generation, which is quite costly for them at this point [117]. For a country like Haiti, where the economy is lacking, it would make a lot more sense to

focus the efforts in the direction of renewable energy, to not deal with that shift and waste more resources later, and to instead leapfrog the traditional central grid model [118], especially since we live in a time that requires immediate action in terms of sustainability.
- The Caracol community could not have survived the results of the 2010 earthquake with a positive comeback without the response of the international community. International help can accelerate the process of rural electrification in developing countries and underserved communities. Awareness programs are capable of bringing the attention towards these communities to attract the financial help of those who can provide it.
- Nourishing a respectful relationship between the customer and the provider can take the electrification initiative one step closer to success. Many organizations tend to forget the social factor of communicating with the residents of the serviced community.

2.5. Malaysia

Malaysia has a high electrification rate compared to other developing countries but there are still isolated islands and communities that require attention, and the renewable energy challenges in it are intensified. Green Empowerment and Tonibung are non-profit organizations working with the help of Partners of Community Organizations Trust (PACOS) to electrify the isolated villages in the Malaysian Borneo rainforest in the country through micro-hydroelectric microgrids [119]. The process of electrification also focuses on the community leadership, and in that sense, it aims to empower indigenous communities as well. The electrification projects of GE, Tonibung and PACOS are not affiliated or registered with the government in anyway.

2.5.1. Green empowerment and Tonibung in Terian and Buayan

To apply for a microgrid system, the community can request installation from either GE, Tonibung or PACOS. These organizations have different responsibilities: GE and Tonibung provide donor funds to cover the cost of installing the microgrid. PACOS has a more on-site role and act as a community organizer to assure that all operations are under control [119]. After guaranteeing the functionality of the microgrid for a full year, the ownership of it is passed to the community, which organizes an institutional committee made up of 1–7 operators, chairperson, secretary and a treasurer [120]. The constitution of the committee is based on the feedback its members receive from their fellow-residents, and it differs from one village to another. All capable villagers contribute with some hours of labor that the project could benefit from, and it adds up to almost 10,000 h per community before the project is complete [121]. In that manner, community empowerment can be achieved. While international agencies and NGOs provide most donor funds to the projects, the labor efforts of the community account for 20–30% of the necessary funding for the projects [122]. For operational costs, tariffs are collected from the customers in the community. Since this microgrid is based on hydropower, these costs are minimal especially in the wet season.

The information on this program is obtained from two site visits to Terian and Buayan villages in the Borneo rainforest. Both villages have micro-hydro power systems that were installed in 2005 and 2009, respectively [123]. In Terian, Buayan and other villages, communities decide among themselves, with the help and leadership of the electrification committee, tariff collections and payment policies. For example, unlike Terian, Buayan allows packaged payments of up to three months; a customer has the option to pay once every month, or once every three months. Fig. 5 shows how customers have different service options that vary by power consumption limits, and the option of switching their power consumption plan to a higher or lower level. The customers in Terian tend to choose lower consumption levels while the customers of Buayan are spread across all levels.

The payment policies that the communities decide also cover punishments in the event of non-payments and/or theft. However, while community members are proven to be efficient in payment collection upon availability, they rarely enforce punishments since they most likely have strong relationships with the customers. In Terian, for example, a cumulative fine is expected to be paid by customers for every month of non-payment, but it has only been enforced once since the installation of the microgrid in 2005 as of 2013 [124].

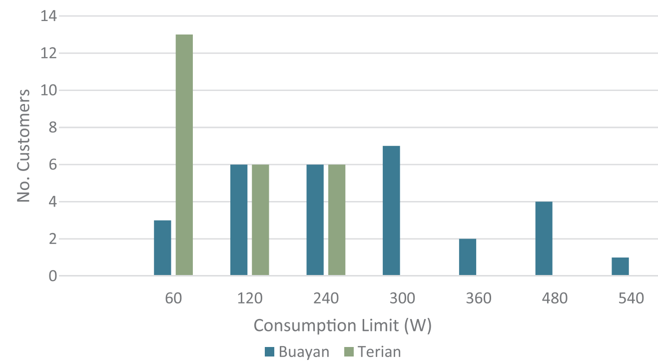

Fig. 5. Number of customers for varying consumption levels in Buayan and Terian.
Source: [107].

2.5.1.1. *Performance*.
In the two villages that have been visited, around half of the households was connected to the microgrid in both cases. Some residents are still not close enough to the installed microgrids, which suggests the need for more than one installed system in some cases. Other residents are merely not willing to pay for the service and do not think of it as necessary in their daily lives. Although only half of these villages are energized, their communities overall show signs of higher standards of living and they own a large range of appliances in their homes. These living standards can be altered seasonally; the hydropower systems do not function as well in the dry season, and require frequent repairs when the river flows are disrupted [123]. GE and Tonibung cover the necessary maintenance cost with the help of the community's voluntary work, which solves disruptions relatively fast. The only issue with performance concerns future load management. As pointed earlier, Malaysia is mostly electrified and has big cities that the residents of rural communities are exposed to occasionally [87]. If only one villager visits the city once in his lifetime and comes back to talk about it with his community, the news on the rapid technological developments of the city will spread out in a matter of hours. With the communities pursuing higher living standards every day and with the non-strict punishment policies, theft and nonpayment levels will keep increasing as demand increases to acquire similar standards and technologies as found in the cities. If nothing is done about this, sooner than later the consumption levels will exceed the capacity of the installed systems and will result in lower performance levels and more blackouts.

2.5.2. Lessons learned from Malaysia

The GE, Tonibung and PACOS initiative showed that the quality of community involvement and ownership can be improved by empowering the villagers through boosting their confidence and trust in their own abilities and building a sense of commitment in them to voluntarily help improving their lives with their own physical and mental capabilities. Other discussed initiatives have instances of community involvement through formal training sessions to maintain the projects in their village, but this initiative differentiate itself from others by focusing on improving the internal self-value and morals of the villagers to be part of the implementation process as well. The GE/Tonibung and PACOS investment in the villagers saved 20–30% of the funds through their willingness to contribute with hours of labor work. This initiative

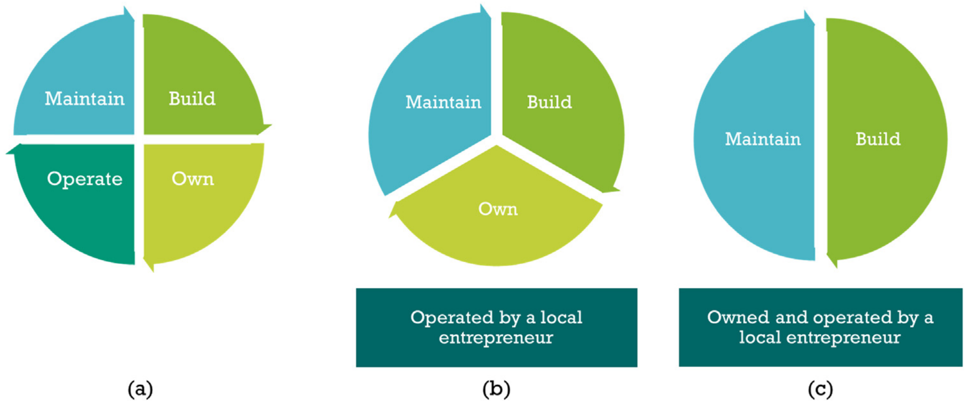

Fig. 6. The responsibilities of HPS in the (a) BOOM (b) BOM and (c) BM business models. The BM model is the most preferable by HPS as it leaves a bigger portion of the organization's effort in the maintenance of the systems.

expected long-term success is because every community put at least 10,000 h of work in the project that it exposed them to every part of it. The community, as a whole, has full knowledge of the project and they are familiar with all the problems that might occur with the microgrid. If the community can prevent the loss of all of its skillful technicians – that tend to migrate to cities – then the electrification system can run for a long time. It is necessary to note that for most villagers, this intellectual involvement could be their first chance to recognize their strengths and self-value and to validate these strength in the eyes of the observer. For example, this initiative proved at times that communities can come up with creative solutions to solve their own problems when maintenance is required, that even the NGOs could not come up with. Besides community involvement, the partnership between the NGOs utilizes a large set of capabilities and resources, and therefore it is highly encouraged especially since their goals are generally similar.

Other lessons can be learned from the weak side of the initiative. As mentioned in the discussion of the business model, penalties for theft and nonpayment are rarely enforced in the villages of the Malaysian Borneo rainforest, since the operators that collect payment as well as the electrification committee are all members of the same community as the customers, and to be forgiving with them. As a result, this shows the importance of strict law enforcement regardless of the bond shared between the customer and the provider. Having a role model, such as the mayor or head of the village, or two competing parties for payment collection without conflict of interest can help with reducing thefts and non-payments [125]. The community voluntary work is mainly due to an internal sense of responsibility, so a similar technique can be used to increase payment rates. A role model that follows the roles and regulations of consumption limits and tariff collections can advise his followers to internally exercise control. In the CIP project in Haiti, customers were more willing to pay than in Malaysia, which might suggest a variation in cultural values that should be monitored, but it is most likely due to punishment enforcement in the first case and not in the second one. Lastly, since this initiative is not registered or recognized by the government of Malaysia, it might lose its right to operate one day due to new laws and regulations by the government, or at least be affected by some governmental penalties [93]. While community ownership can protect the projects from vandalism, getting government recognition or registration can also be important to avoid lawful complications, even if it adds extra fees and taxes to the financial cost of the project.

2.6. India

25% of the non-electrified population of the world resides in India only, which has the second highest population in the world and is considered the third biggest contributor to climate change after China and the United States [87]. Higher electrification growth rate using clean energy sources is crucial in India, not only for its own sake but also for the sake of the world and its sustainability. Sections 2.6.1 and 2.6.2 will discuss two different electrification initiatives managed by two different developers in Bihar, which is one of the poorest Indian states with only 16% electrification rate [126]. Although both initiatives depend on renewable biomass sources for power generation, they deploy different business models and policies and in turn have different strengths and weaknesses.

2.6.1. Bihar – husk power systems

Husk Power Systems (HPS) is a for-profit company that depends on biomass gasifiers for powering its installed microgrids. Within HPS there are three different business models and multiple financial resources that expands the size and reputation of the company. Compared to other developers, HPS has an attractive and successful profitability model, so in terms of financing, the organization receives loans and grants from many different investors that want to benefit from their investment in HPS such as the Shell Foundation, the International Finance Corporation (IFC) and the Indian Ministry of New and Renewable Energy (MNRE), as well as federal government subsidies [127]. The large amount of profit that the company makes allows it to build more systems than any other microgrid developer in Bihar and perhaps India, with 82 fully-installed systems as of 2013 [127]. The detailed explanation of three different business models shown in Fig. 6 is as follows:

1. BOOM: Build-Own-Operate-Maintain: HPS builds the microgrid, operates it, maintains it, and therefore owns it. It is the first business model that HPS used and accounts for 62% of its total installed systems, but is no longer an attractive model to HPS since the operation and maintenance of 51 plants is extremely difficult [128]. Foreign HPS operators in the sites of the microgrids do not have the incentive to visit the homes of the customers for tariff collection and service maintenance as frequently as HPS requires (every two days), which makes HPS obligated to spend extra money on bonuses for the on-site operators, for them to complete their duties. While this model is successful in terms of tariff collections, HPS wants to reduce its spending on the operators, and it moved to the BOM and BM models instead [128].
2. BOM: Build-Own-Maintain: This model is like BOOM, but as the name suggests, HPS passes the duty of operation to a local entrepreneur, while still receiving most of the profit for ownership. This way, HPS does not need to provide bonuses for the operators that work independently and are self-driven to collect tariffs. This model accounts for 21 of the total HPS systems, which corresponds to 25% of all microgrids built by HPS [129].

3. BM: Build-Maintain: BM is the most preferable model by HPS today, because it provides all the benefits discussed in the BOM model, but provides a higher rate of advertisement to the projects. Once HPS gives up its ownership of the and relies it to a skilled local, this operator and now owner has similar if not higher drive to collect tariffs and keep the systems operational and under control [129], but also is more likely to receive applicants if it advertises for ownership opportunities.

Regardless of the business model, HPS does not service communities that are not capable to pay for its facilities, but more importantly, it does not build projects where rice husk is not locally available, to ensure that there will be no extra costs for importing rice husk, which is the main source of power generation in its projects [130]. In the BOOM and BOM models, HPS sets the prices to the minimum possible while still making profit. Naturally, the owner and operator decides the price of services in the BM model, usually by offering something that is cheaper than kerosene but still profitable for them. This makes BM more expensive then BOOM or BOM; nevertheless, its reliability as well as its affordability compared to kerosene attracts customers in these regions.

Given that BM operators have the greatest incentive for collecting tariffs, it makes them stricter than BOOM and BOM operators, and therefore they are more likely to prevent theft and non-payments than the operators in the other models. The way the operators deal with payment and theft problems differently in each model gives HPS another reason to move towards the BM business model. Even so, HPS has many difficulties with managing the number of theft incidents in general in its microgrids; many customers found ways to bypass the meters installed at their homes because of the lack of technologies that can stop over-usage in their sites [130]. To deal with this issue, HPS occasionally blocks power from the entire village, to forward the responsibility of dealing with the villagers who caused theft incidents to the other members of the village that follow the rules [107].

The other method of limiting nonpayment and theft is the simple fact of not servicing those who cannot afford the payments. To keep the systems running, HPS need to have overall profit from its projects, and while that means that not everyone will benefit from the microgrids, the quality of the service to those who have the capability to be customers is high, even higher than it is at the centralized grid [129]. The HPS- built microgrids are extremely reliable, whether they are owned and operated by HPS or not, since the organization is responsible for maintenance in all three models. There are rarely any blackouts or disconnections, besides for a few days in the year for maintenance or if punishments are necessary. The rice husk is cheap and available all year long, in all areas with an HPS system. The biomass gasifiers, however, require a lot of the rice husk, and can be tricky to store or maintain [107,131]. Other than that, there are some technical or maintenance problems that require the attention of HPS, but the organization proved to provide the best level of performance to its customers, that makes their microgrids the optimal choice compared to the few existing and unreliable alternatives. HPS presents a model that focuses on the quality of its service, and does not pay as much attention to quantity of customers, as long as the overall result increases its profitability.

2.6.2. Bihar – DESI power

DESI stands for the Decentralized Energy Systems of India, which is another company in India that depends on biomass gasifiers for electrification but is, unlike HPS, a non-profit company. Most of its installed grids are in Bihar, except for one. On top of providing access to electricity, DESI is another organization that aims for the empowerment of non-electrified communities, like GE/Tonibung in Malaysia [132]. Their focus is on the representation of women as well as the poorest residents of the rural communities in the work field [132]. The mission of DESI is composed of all the universal access objectives, since it measures its success not only based on the number of electrified customers, but also based on the number of jobs created, and the rate of climate change mitigation caused by the usage of renewable energy in rural electrification. Just like HPS, DESI Power has three different business models [107]:

1. The Village Model: This model consists of two stages. In the first stage, DESI aims to enable the villagers commercially by developing some activities and providing commercial equipment for the community, such as battery charging stations, agricultural equipment and commercial workshops. By giving these opportunities to the villagers, DESI makes it possible for them to pay for the electric services that they would provide for the village a few years later. In most cases, the services in the village model are lighting services.
2. The Industrial Model: A model that services relatively bigger businesses and industries, and it is based on selling electricity through a meter reading. The power provided through this model is reliable, which is required for the stability of an industry. There is however, a lack of formal purchasing contracts between DESI and the serviced industries, which is mainly because DESI operates in communities that do not have consistent, unfailing competitors.
3. The Hybrid Model: also known as the semi-urban model, in the middle between a village model and an industrial model; that is, it services small commercial customers like in a village model, but on a metered basis like an industrial model. DESI also delivers energy services such as lightning to the communities under this model.

The implemented model is decided based on pre-development surveys of the villages. Currently, DESI only has microgrids in five villages, and the small number of microgrids (especially in comparison to the number of the microgrids installed by HPS) allows for consistent monitoring and attentive operating in all its sites. On the other hand, the slow expansion of DESI microgrids prevents it from scaling up [133]. This is not necessarily a negative aspect of their business model, because the success of DESI is partially due to the meticulous attention it gives its customers, that could be of lesser quality had the number of microgrids grew with a faster rate than manageable.

There are different levels of energy service for residential customers in each DESI site, and they range from lighting-only to plans that can power refrigerators and TVs. The flexibility of the consumption levels, according to DESI Power, makes the services more affordable to a greater range of residents and leads to stable payment. The success of payment collections is also resulted by diligent collectors that visit residential customers daily and commercial customers weekly [134]. Therefore, non-payment is not a problem at the DESI microgrids, but there is still a risk of theft and overuse in residential houses that cannot be easily monitored. About 2–3 kWh per day is stolen in some cases, which is a significant amount for microgrids that serve poor communities [107]. DESI gives severe penalties to customers that are caught overusing power. In the future, to prevent any cases of residential theft, the company strives to install technological solutions that can detect the electricity usage in households through wireless control networks [107].

As noted earlier, DESI aims to empower poor residents through its programs, but for a non-profit company to keep operating, there is a need for consistent financial collaboration of the customers, and it can be quite challenging to cover the costs if all customers were in poor conditions. For that, the company tries to maximize the number of underserved people among its customers by setting up microgrids in areas that are guaranteed to also have commercial and industrial customers, and from there expanding to neighboring disadvantaged households [135]. Just like HPS, DESI's success comes from providing reliable energy at lower prices than the diesel-powered central-grid in Bihar [136]. The DESI customers are generally satisfied with the reliability and cost of energy they get, as a big portion of them are extremely poor. The DESI microgrids in the Bihar villages connect 70–80% of households on average to electricity [137]. The rate of

downtimes in the case of DESI plants are higher than in HPS plants, which are mainly caused by operating issues, such as problems with underground cables. However, the key value of DESI initiatives in the villages of Bihar are the empowering aspect and job creation that they provide, since at the end, the principal goal for electricity access is improving the quality of life of people, in which DESI appears to do well.

2.6.3. Lessons learned from India

HPS and DESI have some differences and similarities that collectively propose possible policy and implementation variations in the field of renewable-energy-based rural electrification. Both companies recognize the importance of diligence planning and therefore experiment with different models that can be well-fitted for the communities they want to facilitate. Distinct policies and techniques are needed and there is no one solution that can work for all rural and urban communities alike, or even among different rural communities.

In terms of the tradeoff between scalability and management, the two companies picked very different approaches. HPS tried to scale up rapidly but could not take care of the ownership of all its microgrids, whereas DESI focused on a smaller number of plants to own and operate and failed to scale up even after ten years of showing successful results. The HPS BM model appears to provide a balance between scalability and management, especially that they are in fact more successful and profitable than the BOOM and BOM models [138]. Local entrepreneurs proved to be reliable, and depending on them to lead some tasks can help with the scalability of electrification initiatives without losing management quality. Moreover, the intervention of the private sector in the electrification process can show magnificent results. HPS, especially its BM model, shows how the business dynamics between local entrepreneurs and the private sector can effectively speed up the process of universal access.

Another lesson that can be extracted from the Bihar experience is that giving bonuses to workers in rural communities is not a good enough incentive for improvement. This is an example of the backward-bending labor supply curve principal which shows how the relationship between the number of hours worked and rate of wages is not linear [139]. After a certain point, the workers value the extra hours of leisure more than the extra money they would earn due to extra hours of work. The payment collectors for HPS in the BOOM model did not have the incentive to work more diligently in the collection process even after the bonuses they have received. In the case of DESI, a non-profit organization, government support is especially important, a point that is revisited in various of the study cases so far. In Bihar, DESI has been facing issues with expanding its microgrids mainly due to the chaotic central-grid expansion methods that the government trails [140]. Not only is the central grid practically inoperable but it is also considered a determent to the progress of the DESI microgrids as well as other electrification companies in the country faced with similar challenges.

Another important lesson from the DESI experience is the requirement of a focus on powering communities for the sake of job creation and commercial or industrial growth. This is not only for the direct benefit of the individuals that belong to the community, but also for the sustainability of the electrification project financially. If the communities are limited to lightning or charging services only, then the electrical loads on the plants will most likely remain extremely low during the lifetime of the microgrid, and there will be no fluctuation or increase in demand; therefore, the number of customers will be fixed, improvements will be insignificant, and the microgrid will never be able to withstand, let alone to expand.

2.7. Senegal

Although the electrification rate in Senegal has been historically low, it has increased sharply in the past decade, reaching 61% in 2015 [87]. This increase is credited to the 1998 reform by the government of Senegal that allowed the creation of ASER, Agency of Rural Electrification [140]. As the name suggests, this agency is devoted to providing electricity access in rural areas in the country. The government projection of the rate of access is to achieve universal access by 2025 [141]. The next step is expected to be difficult given that the agency has mainly focused on central grid expansion so far, and it is predictable that this method is limited and cannot reach dispersed communities and villages with low density, which are relatively common in Senegal, and have been completely ignored [142].

2.7.1. Experiences from surveys in Kaolack, Fatick and Thies

The Couré Mbatar village of the Thies region in the west of Senegal only has 22 households with an average of 10 inhabitants per household [143]. Nopalu is a locally implemented fee-for-service photovoltaic systems project that was initiated by the chief of the village with the help of a school director. These PV systems provided lighting and charging services after surveying the villagers. Even though this locally-based project met its objectives with reliable lightning and charging, it did not meet the demand of the villagers who have hoped to receive services for a television and a refrigerator [143]. These requests are thus not suitable for the initial design of the project, which suggests a gap between the pre-electrification and post-electrification demands. While the chief of the village does not have the power to create an electrification project of a bigger scale to service the villagers with TVs and refrigerators, it is often that electrification initiatives wrongly estimate the demand of a rural community because they directly ask its members about the desired load profile through surveys. To remediate this issue, a more complex analysis can be done, in which an estimated demand can be extracted.

The Intelligent Energy Europe (IEE) is a program that aims to promote the usage of renewable energy in rural electrification projects in remote villages [144], such as in Senegal and it constitutes of six separate stages, including project management, micro-grid training and analysis of local needs [145]. In the analysis stage, the program conducts more extensive surveys and collects a wider spectrum of information, which factors into its examination instead of simply inquiring after the level of need from the villagers. The surveys have been conducted in the regions of Kaolack, Fatick and Thies in Senegal, and the surveyed consisted of both the electrified and the non-electrified communities in these regions, to account for the perspective of both parties [146]. The inspections aimed to find the number of villages in each region and categorize the villages based on a number of factors, including the most popular economic activities in the village, the number of residents per household in relation to the size of the village, the physical state of the buildings, the number of rooms in every building, and the roof material to identify its compatibility with photovoltaic panels or other electrical accessories. The results showed that the main socioeconomic activity in the villages of all three regions is agriculture, the second main activity is livestock farming, and the third is commerce [145]. Moreover, there is a direct relationship between the number of residents in each household and the size of the village to which they belong. The data on the physical state of the buildings and the number of rooms in each building was taken to help predict the needed length of the electrical cable if the village were to have a micro-grid project, as well as the theoretical number of lightbulbs needed [145]. Other information found through the survey was the kind of energy used in non-electrified villages, which included candles, batteries, butane gas, oil-lamps and solar PV panels with batteries [147]. The surveys also inquired after the types of electrical appliances used by neighboring electrified villages in all three regions, to estimate the level of load in the currently unelectrified ones. Unsurprisingly, the interviewers also asked the non-electrified communities about the level of service that they would want and their willingness to pay, but solely to complement the rest of the data that they collected. The analysis comprised an important piece of data, which is the prioritized services of the village in the case of downtime and blackouts. In two of the three

regions, the mosque had the top priority; in the third region, it was the health center [146]. It is important to note that the interviewers requested answers from the chiefs of the families, which would most likely be a man in a traditional community, and that could have skewed the results of the surveys, as women are less likely to go to the mosque in these communities and they are expected to prioritize health centers more than men. From the composed data and the discovered potential of solar, wind and biomass energy in Senegal, an electrification kit has been designed to suit households of different configurations in villages of various sizes and conditions [146]. While the installed systems have not been revisited to measure their long-term success, and complete the learning experience, the extensive collection of data, based on the community itself as well as it surrounding electrified villages theoretically helped with the development of a focused solution for various regions in Senegal.

2.7.2. Lessons learned from Senegal

A few, particular lessons can be extracted from the Senegalese experience. First of all, governmental reforms of the energy sector are desirable, if not required, in the development and acceleration of rural electrification [142]. Specialization can be beneficial in various scenarios that are less complex than energizing an entire country, and for that electrification projects should not be expected to succeed without having expert entities in the energy sector that can provide that kind of focused effort. Similarly, a community's judgment of their needs is found to be lacking and better ways are needed to estimate demand. In this case, extensive surveys that rely on objective data from the communities can serve as a good alternative, especially when the answers are based on the experience of neighboring electrified villages as well. This is where the IEE project succeeds, except for some of the collected data that is related to the prioritized services in the case of blackouts, which had a bias favoring mosques due to the fact that the interviewees in Senegal were all men. If surveys were to be taken, they should better poll all demographics to avoid bias and construct a fair representation of the village.

2.8. Kenya

Kenya has been another neglected Sub-Saharan country with only 35% total electrification rate and 12% rural electrification rate as of 2014 [87]. Unlike in Senegal, rural electrification caught the attention of the Kenyan government since 1973, when it launched its rural electrification program to sponsor electricity for rural communities, but the energy spread halted at a significantly lower rate than in Senegal, for the same reason of initially reaching a limit on the economic feasibility of central grid expansion [148]. The responsibility of Kenyan rural electrification lies on its Ministry of Energy and Kenya Power Company (KPLC), the main transmitter, distributor and seller in the country [149]. The government controls half of KPLC's shares while private investors are shareholders of the other half [149]. After the initial halt, the government launched in 2015 another program called the Last Mile Connectivity Program, which has the objective of universal access set for 2020, through a low voltage network that utilizes the installation of transformers connected to the national grid all throughout the country, with the help of micro-grid renewable energy sources [150]. Since the Last Mile Connectivity project is still under progress, a previous community based micro-grid project in Kenya, the Mpeketoni Electricity Project, will be analyzed to explore the characteristics of electrification in a Kenyan rural village, its effects on the community and its performance to measure its feasibility as a Sub-Saharan micro-grid prototype.

2.8.1. Mpeketoni electricity project (MEP)

MEP is a micro-grid system set in Mpeketoni village of the Lamu Island in Kenya, which had been established in 1993, and has been running since then until the KPLC took over it and replaced it in 2007 [151]. The microgrid is powered by diesel, and does not utilize the abundant renewable wind and geothermal energy that Kenya possesses. The microgrid was a joint effort between the Mpeketoni community that contributed with 30% of the capital cost of the project and the German Technical Cooperation (GTZ/GASP) that sponsored the program and covered the rest of the capital cost [151]. GTZ/GASP also helped the Kenyan government with the initial resettlement project of Mpeketoni in 1972, and supported various infrastructure projects such as roads, education and health centers and water supply [152]. The Mpeketoni resettlement has high agricultural capabilities as well as a wide range of small and medium-sized entrepreneurs (SMEs), including tailors and carpenters [152]. The existing infrastructure along with the development of the micro-grid system allowed the well-equipped settlement to make good use of the electricity that it was supplied with through MEP, and the two complemented each other strikingly.

The data on the performance of the project was extracted from GTZ/GASP records of the project, especially technical and financial data, and it was accompanied by information given from interviews with locals, particularly those who lived in the village before the development of MEP [153]. The microgrid had an overall satisfying performance as it functioned daily between 5-am to 12-am [153]. The highest levels of load occurred during the evening, in which households mostly contributed to that load, while the SMEs were the major contributors to the load in daytime, due to the usage of motors and welding machine during business hours [154]. Tables 4 and 5 highlight the impact of the MEP on the local community in terms of SMEs revenues. The impact was very promising; for carpenters and tailors, the rate of production with electricity in comparison to the production without it significantly increased, so did the overall productivity of the workers. At the same time, the price of the sold products decreased, if only even slightly, which reflects a positive impact on the customers as well. Since the number of units produced per day increased in a higher rate than the rate of reduction of its cost, the daily profit of the MSEs naturally increased as well. The highest increase in revenue comes from the production of stools and beds for carpenters and the production of men trousers for tailors, at a gross revenue increase of 70% per day. Farmers also largely benefited from the accessibility to activities, which is of a great importance to a settlement like Mpeketoni, where most of its main activities are agricultural. Before having energy access, the farmers could not rely on tractors for tillage but more traditional manual tools such as machetes and axes [155]. The only mean for getting tractors in Mpeketoni was to rent them from neighboring settlements that are

Table 4
Impact of MEP electricity on the production and revenue of local tailors in Mpeketoni [101].

Typical Tailoring product	Production with electricity		Production without electricity		Increased productivity per tailor	Impact indicators	
	Average production per tailor per day	Average unit price (Ksh)	Average production per tailor per day	Average unit price (Ksh)		Price reduction per unit	Increase in gross revenue per day
Men pair trousers	8 pieces	500	4 pieces	600	170%	17%	70%
Men suit	1.5 piece	1700	1 piece	2000	50%	15%	30%
Women dress	6 pieces	200	4 pieces	250	50%	20%	20%
School uniform	10 pieces	150	5 pieces	200	100%	25%	50%

Table 5
Impact of MEP electricity on the production and revenue of local artisans in Mpeketoni [101].

Typical carpentry product	Production with electricity		Production without electricity		Increased productivity per tailor	Impact indicators	
	Average production per unit per artisan	Average unit price (Ksh)	Average production per unit per artisan	Average unit price (Ksh)		Price reduction per unit	Increase in gross revenue per day
Stool	3 h	300	6 h	350	100%	14%	70%
Bed (6 × 4 feet)	1 day	4000	2 days	4500	100%	11%	70%
Sofa set	3 days	7000	5 days	8500	67%	18%	40%
Door (6 × 3 feet)	1 day	2000	1.5 days	2300	50%	13%	30%
Window (3 × 3 feet)	1 day	2000	2 days	2200	100%	9%	20%
Coffee table	1 day	1500	3 days	1700	200%	12%	20%

hundreds of kilometers away, and only a few tractors were available for rent, which steeply amplified their demand and consequentially delayed their reception by months. After the start of the MEP, electricity allowed for local ownership of electrical welding services to maintain tractors [155]. As a result, more tractors became available in the vicinity, and the farmers started to cultivate more with less effort and in a timely fashion.

In 2007, the KPLC, through the Kenyan government, replaced the microgrid in Mpeketoni with another diesel-based system that is larger and is capable of servicing Mpeketoni and the neighboring villages that could not be reached by MEP [156]. The performance of the system increased as it operated 24 h daily [156]. Nevertheless, the national utility did not have to start the development of the project or measure the local needs, as MEP was already well-established before the government took over the electricity generation in the village. The expansion of MEP serves as an example of the potential of international effort to jumpstart the rural electrification growth in a developing country.

2.8.2. *Lessons learned from Kenya*

MEP demonstrated success in multiple factors as a microgrid system. It showed the importance of electricity in creating jobs and increasing the overall profit of SMEs, farmers, and the economy of the region in general. With electricity, workers needed to deliver less effort for the same amount of profit and customers had to pay less for the same quality of products. Nevertheless, the benefits of the microgrid installment could not have been achieved to the same extent had there not been an existing infrastructure before electricity became available. Since GTZ/GASP helped with the development of the physical and social infrastructure in Mpeketoni, it allowed for faster growth in the village.

One of the biggest factors of long-term success of an electrification project is its capital cost recovery, and while MEP did not ever reach 100% recovery due to the government takeover in 2007, it did reach 94% recovery that year which is a substantial amount of the cost and it suggests that it would have taken only a few more years before the achievement of that goal [154]. MEP had a positive cost recovery experience most likely due to the energy legislation in Kenya at the time that allowed electrification investors to charge tariffs that cover the cost of operation. [157] Another reason relates back to the first point of having an existing infrastructure before developing the microgrid in the area. The customers could pay for the service provided to them only because of the increase in local revenue that is a direct result of GTZ/GASP empowerment of SMEs in Mpeketoni. When the government took over the project, it was reputable, which suggests that international support can be beneficial to at least jumpstart an electrification project, and then the long-term growth can be carried on by the government.

While the microgrid in Mpeketoni is diesel-based, research shows that Kenya has about 7000 MW of non-used geothermal energy, if not more, as well as a substantial amount of biomass and wind energy [158]. From a technical standpoint, diesel-generators can be very inefficient, and the power they run at goes low compared to its rated power efficiency, which has a negative effect financially and environmentally [101]. The fast pace of the Last Mile Connectivity project in the country can prove as an example of the capability of reducing the expensive cost of diesel generation in a timely manner, while delivering respectable results [3].

3. Discussions

Some of the lessons learned in this paper are particular to the experience of each country, but various others recurred in multiple cases, which are important to note and absorb. Generally speaking, developing countries should take advantage of the leapfrogging strategy and not follow the same path as developed countries that have diesel-based electrification and hoping to shift to renewable energy sources today. This can ensure faster and less expensive development for developing countries as well as better environmental results globally [159,160], especially because their diesel-based central grid is relatively vulnerable and quite overloaded. This can create similar results as mobile phones, a leapfrog technology in the developing world that saved them the trouble of investing in landline infrastructure [161].

From the experiences in Brazil and Haiti, the role of cooperating with researchers and academic institutions can be inferred. Research and development teams can provide structure to an electrification project through their contribution in the planning stage, as well as statistical data that can lead the project in the most optimal direction and prevent it from falling in dire situations. Another lesson from Haiti is the cruciality of planning before grid development to avoid overestimating the demand of the customers and aimlessly spending on the large generator and its fuel. Providing enough time in making size measurements of the generators is important, as it helps with the long-term cost recovery of the project, and the customer satisfaction and willingness to pay. An organization like HPS, a for-profit organization, generally dodges this issue to maximize payment reception and consequently their profit. This can be done through extensive research and finding alternate ways to traditionally administered surveys. This is confirmed by the discussion on Senegal, where we observe that alternatives model for predicting the power usage of a certain community should be considered to accurately project their demand.

In most case studies, particularly in Fiji, the importance of maintenance is emphasized. This can be achieved by either training locals so that their faith in technology is not lost, or having local agents to maintain the systems. The latter is proven to be more difficult as most skilled technicians refuse to work in rural areas when they can receive a better job in cities. Similarly, trained locals might be tempted to use the knowledge they gained from training to find jobs in urban areas of higher living conditions. Some programs, then, intentionally train individuals in the community that are less likely to leave their village, such as elderlies. An issue that rural electrification developers can face is the tradeoff between scaling up and developing a large set of projects, or developing less and leaving more room for maintenance per project. This compromise is discussed in the business models of HPS and DESI in the Bihar region in India, and the most sensible model is found to be the

BM (build-maintain) model of HPS, that leaves the ownership and operation of the project in the hands of local entrepreneurs, and allow the organization to focus on preserving them and their functionality while expanding and reaching new regions quickly.

In many of the case studies, especially the GE, Tonibung and PACOS initiative in Malaysia, community involvement and empowerment shows long-term success. Feeling committed to the success of the project can combine the efforts of every individual in the community to ensure long-term electricity access, and to improve the quality of their lives. Examples from India, Kenya, and the Charcoal Industrial Park in Haiti can support the direct relationship between electricity and quality of life. In each country, focusing on energizing the rural regions with the purpose of economic growth met its objectives positively, and helped with the recovery of the capital cost. Especially in the Mpeketoni settlement in Kenya, where an infrastructure was already set before servicing electricity, the growth was rapid.

The examples from Bangladesh and Haiti mention instances of the impactful role of politics on the implementation and success of electrification projects. Political favoritism is not unlikely, when the electricity generation and transmission is the responsibility of the national utility. On a larger scale, the type of government, whether it is a monarchy or a democracy has a significance, since for example, democracies tend to put a more significant effort in fulfilling their promises to the people during voting periods, to increase their popularities and their chances of winning the elections [162]. Besides political power, governments are capable of contributing to the universal access of electricity in their countries by supporting renewable energy policies and making reforms to bring attention to rural electrification, as shown in Bangladesh and Senegal, respectively. Rural and urban areas face different challenges in development and, hence, they require the adaptation of different sets of policies.

4. Design considerations for first access systems and future research directions

Considering the different cases discussed earlier, it is possible to identify some best practices with good outcomes. Also, it is possible to extract some general take away points which can be used in designing a future first-access solutions. These best practices are intended to show what kind of decisions by the utilities or policy-makers resulted in efficient and sustainable implementations. Developing a one-size-fits-all recipe for first-access systems is not possible due to vastly differing social, political, environmental and technical background of each individual site. It is hoped that these lessons can pave the way for successful implementations that are somewhat similar to the cases that are studied herein.

There are several highly influential factors that are vital to success of a first-access system. As far as the success of a system is concerned, this study considers a full implementation of the system as well as its continuous operation that is sustained on its own. Projects that are implemented with large grant moneys for a short period of time and left to its demise once the grant period is over are, by no means, considered as successful first-access projects. These factors can be detailed as follows:

1) Stable policy environment with long-term outlook
2) Continuous technical support for operations
3) Flexible outlook to technical options, rather than a fixed solution approach
4) Building a financial model that is suitable for the project type

One of the most important lessons learned from all pilot projects around the world is that there policy-makers should create an environment where there are clearly-defined future directions. It is as important that these directions are not changed frequently so that investors or project developers can have a sense of security as they are financing and building the projects. These future directions may differ among communities, sites or countries. For instance, some countries may stick to private entrepreneurship for such systems, e.g. Tanzania and India, while others may opt for government-financed microgrids, e.g. Kenya. The prior solution makes financing much easier and it is easier to reach more people in a shorter period of time. On the other hand, this will create a price inequality between different communities and the latter solution can be used to mitigate that. It is important that policy-makers make a decision according to their principles and keep it constant so that project developers, financers and, even, customers feel comfortable about committing to these solutions as they appear. Worst practices in this area include governments declaring specific sites as off-grid solutions and, then, extending the central grid to the distaste of private companies who developed stand-alone microgrids trusting the government's previous policy. These kind of policy shifts definitely create huge financial problems for the projects on the ground, however, the real impact is the distrust that appears toward the policy-makers and their decisions. Same considerations apply to other schemes such as tax-incentives for specific technologies, feed-in-tariffs or buy-back guarantees by the government.

Second important take away from the study of these projects around the world is that technical know-how is as important during operation as it is in the initial development state. Some first-access systems put huge technical information on the project development, equipment selection and sizing. However, the after-installation maintenance was neglected. After the first year of operation, these isolated sites started having maintenance issues which led large-scale system failures. Majority of these issues where easily mitigated by trained personnel on site. The best practices adopted on different cases are different. Some projects opted to have their own dedicated personnel who visit different sites regularly. This is suitable for first access systems that are run by for-profit-companies who can hire such personnel, e.g. Meshpower of Rwanda, or government-owned projects where such personnel can be easily found, off-grid microgrids of Kenya. An alternative solution is to train the local people to act as local support. This can be more attractive to community-owned systems e.g. the infamous grandmothers of Tanzania, or franchise-model adopted by Husk power in India. The previous solution has higher costs and requires continuous travel, while the latter solution has the danger of locally-trained people migrating to cities in search of higher-paying jobs. Specific solutions need to be selected according to the needs and opportunities of the specific site in question.

Thirdly, project developers and policy-makers need to have a technology-agnostic approach. That is to say, while they may have preferred solutions in-mind, they should be open to alternatives which may turn-out to be more feasible, more cost-effective, or both. These may change as the projects develop as well. For instance, in Brazil, the initial phase included grid-extension to communities that are located closer to the transmission lines. However, as the projects developed, number of such communities diminished while there still exists un-electrified communities in the isolated Amazons. It is important that policy-makers and project developers/companies keep up with the current situation of the projects and adapt the solutions accordingly. Furthermore, there are several stereotypical coupling in the sector such as governments only doing centralized grid while microgrids have to be community-owned or privately-funded. As the case in Kenya has proven, it is possible to have microgrids that are run by the government with good operational results. Experiences in countries with very weak central grid, such as Uganda or Nigeria, show that it is also possible to have a solar home system where such central grids exist. Finally, the evolution of these technologies show that having a transitional or evolutionary energy sector planning is key to achieving very high levels of electrification in underdeveloped countries. Solar home systems, community-level microgrid, large-scale microgrids and national grid can be considered as different building blocks of a healthy energy ecology, rather than separate competing entities.

Finally, all best-practices studied showed that having a financial model that supports the continuous operation of the system is indispensable. Coupled with the continuous technical support capacity, this item has been the deciding factor for most of the early, grant-funded projects. Funded by large institutions such as World Bank or European Union, large systems have been installed. Once the initial installation fund is used up, the project and its assets are left unfunctional. The solution that arises from the studied cases is the ability to create a business-model that can finance long-term operation. In some cases, such as Haiti, it may rely on international support after a large-scale disaster while others may use government support such as electrification of isolated first-nation sites in Canada, or result-based grant money that is utilized in Malaysia or purely profit-oriented as the most successful cases show such as those in Tanzania, India and Bangladesh. While the profit-oriented solution has the biggest business motivation to succeed, in some cases where the purchase-power is not sufficient, or the initial project development requires extra work, focusing on result-based grants can be coupled with profit-making schemes. This facilitates financing of the overall system at first, and guarantees the long-term operation with profits during operation.

In short, different sites have different characteristics which are formed by the geography they are located in, the country they are governed by as well as social and financial features of its society. There is no silver bullet solution that can be developed for all sites. However, as more sites are implemented and best practices are documented, more knowledge is acquired and similar solutions can be implemented for similar features between an operational and candidate site. For instance, if a candidate site is located in a country which support government-run microgrids, then the business and operational model of an operational site, such as those in Kenya, can be taken as a reference site. Similarly, if a site has a very strong community leadership which makes it very hard for foreign companies to enter, then a community-based microgrid site should be taken as a reference case. In such projects, designing the technical support around local community training holds more importance. Also, financing schemes in such solutions have to go through community leadership where external grant is distributed through the local leadership. In such cases, payments need to be collected through them as well. Similar modeling can be developed for other sites by mapping their features to features of sites studied and documented in this paper.

Table 6 is developed as a guideline for new projects. It includes the factors that are vital for a successful first-access implementation, the domain they relate to, what are the requirements for this factor to have positive impact, best cases and possible problems from experience as well as the sites that are studied herein and are relevant to this particular factor. Future research work items can be identified as follows:

1. Technically, versatile and compact solutions should be developed. Especially, solutions that have the ability to work in AC and DC can be very helpful to solve the transition problem. Furthermore, rather than a fixed solar home system, or a microgrid solution, modular systems that can start small and build on as they grow can solve the initial cost problems. Smaller inverters with more advanced capabilities, smaller PV panels with higher efficiencies and innovative small-scale power system designs are required for mass implementations. Furthermore, technical challenges include DC microgrid protection and low-voltage AC protection where generation is connected to loads through a very short lines.
2. For policy directions, it is very clear that governments need to have clear, concise and publicly-available policies for their energy sector. As discussed above, different sites and communities may have different suitable solutions, but these need to be clearly mentioned in the policies. Another important thing is to keep these policies stable so that project developers and investors can work through their projects. Constant changes discourage people from committing to a solution and opt for wait-and-see approach. One solution that seems

Table 6
Factors Impacting the First-Access success.

Factor	Domain	Requirements	Best Cases	Problems	Reference Sites
Policy Stability	Policy Making	– Stability – Clarity – No unexpected changes	– Stable, clear and long-term policies – Public announcement of such policies and refraining from frequent changes	– Frequent changes causes loss of investment and loss of trust – Investors become very reluctant, even if there is potential or purchase power	Brazil Bangladesh
Technical Support	Operational Planning	– Ensuring Maintenance – Capacity building in local communities	– Maintenance by for-profit companies who will make sure the system is running for gains – Community-based solutions with local capacity building projects, special attention paid to people that are unlikely to migrate to cities	– Inefficient operation, large investments turning into dead assets – Effects scalability and duplicability for future projects – Locally trained people may migrate in search of better opportunities (local technician is lost)	Fiji India
Technology Flexibility	Technical Planning, Policy Making	– Technology agnostic approach – Not being fixated to only renewables or diesel as a solution – Not being fixed at central grid or microgrid as a single solution	– Ability to compare central grid and microgrid solutions equally – Picking more cost-effective or feasible solutions, even if they are not renewables	– Trying to fit a certain solution to all sites slow progress, sometimes stalls it – Open-minded approach diversifies solutions while the opposite restricts options to very expensive ore difficult ones	Haiti Kenya Senegal
Business Model	Business, Social	– Social norms have to be taken into account – Business model needs to ensure long-term operation – Willingness to pay and customer purchase power should be taken into account	– Including social leaders during planning and operation phases – Considering the purchase-power and willingness-to-pay in the community – For non-profit operations, clearly set goals for cost-recovery with external audit	– Projects cannot be successfully implemented against social distaste, even if they are technically very advanced and have environmental benefits – Systems should be gradually introduced with higher pay for higher benefits, especially, if the purchase power is very limited – Non-profit systems may plunge into bankruptcy very quickly if finances are not well-maintained	Fiji Malaysia India Kenya Haiti

to be working is refraining from protecting the monopoly of the national grid operator, unless it is ready to fully commit itself to rural electrification and first access systems. Policy-makers need to give priority to for-profit organizations as they tend to have better performance and longevity due to their interests. If non-profit community-based systems are opted for, policy-makers need to make sure there are institutions in place to follow finances closely. Otherwise, systems may quickly become inoperational.

5. Conclusion and future work

This paper presents 12 case studies of rural electrification initiatives in eight diverse developing countries, to extract lessons grounded on past experiences for future work in this field. While the paper's focus is RE off-grid solutions, it also discusses central grid extension approaches and electrification systems with diesel-generators, to contrast cases of different nature and to provide a wide range of rural electrification practices. While all the lessons derived from this review are pertinent, there is unexplored potential mainly in rural electrification demand projection. Most rural electrification projects have been based on pre-implementation data extracted from the community's judgment of their needs, and the measurement of the socioeconomic value achieved through the development of the projects has also been based on the community's opinion after the implementation of the project. These results are usually non-optimal since, as traditionally observed, un-electrified communities do not have the capability of estimating their post-electrification demands. The comparison of different surveying models in Senegal suggest a need for finding better ways to gauge demand rather than surveying the to-be serviced community only. Future work requires extensive research in the estimation of post-electrification behavior of a region by comparing it to other electrified areas with similar parameters. Developing a model that can advance RE-based rural electrification policies aligned with the projected demand of rural communities and quantify the socio-economic value of the process of electrification even before it begins, can pave the road for major development in the field of rural electrification with renewable energy.

Acknowledgements

This work has been supported by Carnegie Mellon University, Scott Institute's Power System Research Grant 2017.

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